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Chapter 11

Uniformitarianism versus Catastrophism

Principles of Geology

In December 1831, the young Charles Darwin (1809–1882) embarked as naturalist on the *Beagle*'s voyage around the world. Among the books he carried with him was the first volume of *Principles of Geology*, published a year before by Charles Lyell (1797–1875). Although "the sagacious Henslow," Darwin's professor of botany, "had recommended the book to him with the reservation not to accept any of the ideas," he was fast under the spell of Lyell's ideas. After his first observation of geology, he "was convinced of Lyell's infinite superiority of ideas."[1]

These ideas are traditionally summarized by the word "uniformitarianism," or by the term "present-day causes"—both explain that the "present is the key to the past." In opposition to geologists of his time who saw traces of former catastrophes everywhere, the author of *Principles of Geology* attempted to explain "former changes of the Earth's surface, by reference to causes now in operation."[2]

To embrace such an idea, it was certainly necessary to become aware of the great duration of geologic time. This is exactly what Charles Lyell did during his travels, which brought him in 1828 to France and then to Italy.

Born in Kinnordy, Scotland, the future geologist learned to observe and collect insects in the countryside. In 1818, after the customary classical education, he attended lectures on mineralogy and geology given by William Buckland at Oxford. His interest in geology was aroused. In 1819 he was elected member of the Geological Society of London; from then on he maintained his interest in geology while continuing his studies and practice of law.

In 1823 he spent two months in Paris, where he met many French scientists, but it was not until 1828 that he went to see geology for himself. Accompanied by Roderick Impey Murchison, he traveled through Auvergne, where he became particularly interested in stratified freshwater deposits. Observing layers thinner than one millimeter, he attributed each layer to an annual deposit and calculated that the entire series of layers (230 meters) must represent hundreds of thousands of years of deposition.[3]

His *Principles of Geology* reaped immediate success. When volume 3 appeared in 1833, the author had already revised the first two volumes (published in 1830 and 1832, respectively). In 1834 he restructured the entire work into a new edition in four volumes.

In 1838 Lyell published *Elements of Geology*, applying uniformitarian principles to the history of the earth.[4] The two works were revised several times before his death. Although Lyell is still considered the father of geology in many textbooks, or at least the man who popularized Hutton's ideas, I shall compare below his main ideas with the work of his contemporaries.

Constant Prévost

To start with, uniformitarianism was not Lyell's invention. Constant Prévost (1787–1856), whom Lyell had met in Paris in 1823 and who, together with Ami Boué (1794–1881), was the founder of the Geological Society of France, had mentioned the same ideas in opposing Cuvier's school. As early as 1821 Prévost observed "a mixture of marine and fluvial [i.e., from rivers] shells in the same layers" in the hills of the Paris Basin.[5] This fact shed doubts on the repeated marine invasions postulated by Cuvier and Brongniart. Prévost believed that marine shells found above the "calcaire grossier" (coarse limestone) might be merely "reworked" fossils; that is, remains from that formation which had been exhumed by rivers and introduced into later deposits.[6]

Modern geologists know how easily the phenomenon of reworking can mislead them in the dating of a rock layer. Careful examination is necessary to find traces of abrasion, of having been transported some distances, or of a matrix from an earlier deposit. But in 1820, such detailed observations were not conceivable, and Prévost's remarks show fair caution.

Without even considering reworking processes, river mouths and estuaries are also known to show mixtures of marine and freshwater faunas similar to those Prévost thought he had found in the Cenozoic layers in the vicinity of Paris. He thus doubted the theory that present lands "have been several times covered by the sea" and preferred the old concept of the universal retreat of the primitive ocean.[7]

Prévost was thus a uniformitarian when he looked for present-day equivalents to what he observed in rock units and also when he refuted "revolutions on the Earth." Nevertheless, he did this in a curious fashion, taking advantage of some mixtures of marine and fluvial species in order to deny the alternate superposition of layers formed in the sea and in freshwater. He spent his entire career working on a "theory on tributaries," according to which two parallel types of deposits had existed through geologic times: a marine type formed essentially by limestones and a fluvial type consisting of coarse rocks such as sandstones. Superposition of the two types occurred only when they met, namely, at the mouths of rivers. Hence, during the Cretaceous, for instance, deposits of green sands and clay, called "Gault" (which occur in reality underneath the Chalk), were interpreted by Prévost as a formation of the same age as the Chalk. It happened to be underlying the Chalk locally only where estuaries deposit sand and argillaceous mud.[8] Prévost's approach shows one of the pitfalls of uniformitarianism. Based on present-day causes, he tried to prove that **transgressions** of the sea had not occurred, which is, in fact, a step backward.

Uniformitarianism

To understand uniformitarianism, or the principle of present-day causes, which rules contemporary geology, we should perhaps separate two ideas associated with that concept: continuity and equilibrium. When William Whewell (1794–1866) coined the word *uniformitarianism*, he meant to describe Lyell's doctrine; catastrophism was, according to him, the opposite theory. Thus, Whewell emphasized only the degree of violence in phenomena invoked in the two theories.[9] However, instead of uniformitarianism and catastrophism, I believe that continuity and discontinuity better describe the two opposing theories.

Continuity

Uniformitarians certainly fought for the concept of continuity in the earth's history. This is shown, for instance, in a debate between Prévost and Dufrénoy at the Geological Society of France in 1833. Dufrénoy wanted Prévost to admit that it was possible to separate the Tertiary era into three periods, each one with its typical fauna. Prévost gave in, on the condition that Dufrénoy recognize intermediate stages.[10] In fact, continuity in transitional stages meant refutation of violent catastrophes. Indeed, if transitions were slow, causes could be found in present-day processes.

Something similar happened to Darwin when he observed coastal uplifting in South America. Noticing that the shores of Chile had been elevated "imperceptibly" after the earthquake of 1822, he concluded that "earthquakes, volcanic eruptions, and sudden uplifting of the Pacific coast must be considered irregularities of a much larger phenomenon."[11] In other words, even discontinuities observed in *present-day* processes were suspected of not expressing the essence of geologic phenomena. One might almost talk of super-uniformitarianism!

Equilibrium

Continuity was only one aspect of the theory of uniformitarianism. Lyell believed that both variation and its effects were uniform in intensity. More precisely, according to him the world was in a relatively stable state. Martin Rudwick qualified this concept as the "steady state model."[12] In other words, we could say that Lyell was a believer in both "steady state" and uniformitarianism.

The opposite doctrine was the directionalism of catastrophists, who assumed that the world evolved in a specific direction. We could perhaps use the simpler term of evolution if it were not apt to cause a possible confusion with Darwin's evolutionary biology.

In the first edition of *Principles of Geology*, Lyell believed in the stability of the living world. Of course, some species disappeared, while others were created; but species were somehow replaced by very similar forms, which were used for dating but did not change

the general equilibrium.[13] And all this was done with discretion for the sake of continuity.

Prévost adopted very similar views. He was forced to recognize that, at the level of species, "ancient organisms of all classes are different from present ones." But he added immediately that "the physical structures of ancient organisms are not essentially different from those of present organisms."[14] Therefore, the latter "could have adapted to the environment at the earth's surface when the Late Paleozoic rock units were deposited."[15]

For or Against Physical and Biological Stability

Uniformitarians wanted to prove the stability of the physical world. Across many centuries, their arguments joined those of Aristotle. They believed in variation, but also in processes that compensated for each other so that, on the whole, nothing changed except for a few minor details. In 1830 there was no reliable way to reconstruct the early history of the physical world, but faunas seemed to offer the best tools. It was well known that organisms had changed over time, and stratigraphy used fossils with increasing success to date rock units. However, to demonstrate an approximate stability of the physical world, it was sufficient to show that biological organizations had remained quite similar.

Who supported the opposite view? Catastrophists? Yes, certainly, because Cuvier stated that variations of the "liquid" "caused" faunal changes.[16] But they were not the only ones to postulate variations in the physical world. In 1835, Étienne Geoffroy Saint-Hilaire (1772–1844) claimed that if ancient fossil species returned to earth they would die because "the present environment would no longer provide required conditions for their respiration."[17] Geoffroy was a transformist. A disciple of Lamarck, he was the most respected supporter of the transformist doctrine of the time. The controversy over the unity of biological organization, which pitted him against Cuvier at the Academy of Sciences in Paris in 1830, would have distressed the old Goethe, who had studied the same subject.

The Novelty of Catastrophism

In 1838 it was believed, as Jean-André Deluc had said forty years earlier, that the physical and the biological world proceeded according to a "synchronous" history.[18] When Deluc began his battle against uniformitarianism, he coined a new term to describe what appeared to him the traditional methodology in geology. Although, as we mentioned in chapter 10, he was the first to use the expression "present-day causes," the notion was obviously so accepted by everyone that no explanation was necessary. He rejected the uniformitarian methodology because he had observed that the earth had changed, both biologically and physically, and that the physical changes had caused the biological.

Cuvier (borrowing from Deluc without giving him credit) used the same expression to stress his disapproval of his predecessors, who "had believed for a long time that they could explain present-day causes by former revolutions. . . . However, the chain of events has been broken."[19] Cuvier thus emphasized both discontinuity and directionalism. According to him, ancient causes had been more powerful and they had acted upon a different nature, in particular, on a "liquid" (ocean) of different composition. Whereas Deluc was content to underline directionalism, Cuvier wanted to find changes both in the intensity and in the nature of former causes. He thus replaced transformation of species by catastrophic faunal changes.

In short, in Deluc's day, the late 1790s, the concept of uniformitarianism was considered to be an old method that had been used for decades and was based merely on common sense. How did Lyell turn it into a novelty?

Innovative Uniformitarianism

Back from Sicily, Lyell told Murchison in 1829 that "*no causes whatever* have from the earliest time to which we can look back to the present ever acted but those *now* acting & that they never acted with different degrees of energy from that which they now exert."[20] He thus took the opposite view of Cuvier. While he pleaded his cause in the three volumes of his book, he also established a new methodology. The first volume of the *Principles of Geology* described current geological changes at the surface of the earth, from the effects of rain to those of earthquakes. Lyell emphasized processes "acting now" because they had been too much ignored by his contemporaries. Cuvier had rejected the doctrine of present causes in a few pages because he did not know much about it. Lyell, in turn, asked his readers to observe these processes, and he was certainly right to do so.

A simple confirmation of present-day causes was, however, not enough to create geology, as some biographers of Charles Lyell have too often stressed. A good illustration of the limits of the uniformitarian doctrine is the case of the zoologist and paleontologist Henri Ducrotay de Blainville (1777–1850) in France.

Retrogressive Uniformitarianism

Blainville believed that "extinct groups have perished because of natural causes which are still active presently" and not by a "general revolution."[21] But because he naively believed in final causes, he could not admit that species changed according to circumstances, nor that they could have been created successively. According to him, the animal world formed an unbroken series (or a chain of beings) that did not allow piece-by-piece creation or repairs. For Blainville, only one solution remained: all species were formed at the same time, and fossil forms are those of species that have become extinct since Creation—a retrogressive thesis at a time when every paleontologist could observe that many present-day species were not found in the oldest rocks. Whereas Blainville's retrogressive uniformitarianism was only an unlucky offshoot of the doctrine, the weaknesses of Lyell's tectonics created even greater problems.

Lyell on Mountains

Lyell did not seem to care much about the formation of mountains, or at least was unable to take a stand. It is surprising that, even in the tenth edition of *Principles of Geology*, he compared the formation of mountain chains to the general uplift of the Scandinavian countries.[22] This shocks the modern reader who knows that northern Europe is rising because of isostatic adjustment due to the melting of the ice cap that covered the region during part of the Quaternary. Based on the fact that the upper parts of the earth float on more or less viscous lower parts, the theory of isostasy says that the melting of ice has the same effect as the unloading of a ship. Such a movement cannot be compared to that which uplifts mountains by folding.

It is true that the idea of uplift in the northern countries impressed many naturalists at that time. Following Celsius and Linnaeus, the moving shorelines of the Gulf of Finland were attributed to the retreat of the sea. At the beginning of the nineteenth century, von Buch demonstrated the existence of uplifting movements.[23] But most naturalists remained skeptical. In 1834 Lyell took a trip to see for himself and was convinced.[24] Soon after, Élie de Beaumont presented a paper by Auguste Bravais (1811–1863) to the Academy of Sciences in Paris where he showed clearly that the ancient shorelines were deformed, a fact that could not be explained by the simple retreat of the sea.[25] Therefore, Sweden and Finland were in fact rising.

Of interest to uniformitarians was the fact that this movement was *slow*. If such a condition could be applied to any uplifting, then catastrophes would be excluded and mountain building could be explained by century-long movements. But how was it possible to explain this uplift?

Before the theory of isostasy was first presented in 1855 (see chapter 16), Lyell could at best explain slow uplifting by expansion of the earth's crust by heat. Heat and chemical reactions, he said, would "give rise to a mechanical force of expansion capable of uplifting the incumbent crust of the earth, and the same force may act laterally so as to compress, dislocate, and tilt strata on each side."[26] Catastrophists must have been baffled by such ignorance of the importance of folding. Murchison, Lyell's former travel companion, described in 1849 overturned rock masses and thrusts in the Glaris Alps that needed other types of lateral compressions.[27]

Elements of Geology proposed another solution, giving the impression that Lyell paid little interest to the question in the first place because he had a different answer ready whenever needed. However, this answer was not any more satisfactory. Having observed local collapse in coal mines, he concluded that "similar changes may have occurred at a larger scale in the Earth's crust."[28]

Metamorphism

It was easy, however, for Lyell to triumph over earlier neptunistic ideas in regard to the origin of igneous rocks and the recognition of metamorphic rocks. Here rested probably the great novelty of the uniformitarian school.

Werner believed that granite and metamorphic rocks (gneisses, micaschists) were primitive rocks formed under conditions that no

Metamorphism

Metamorphism means transformation of rocks at depth under the effect of temperature and pressure. Minerals of sedimentary rocks, formed at the surface of the earth, become unstable with increasing depth. During orogenic phenomena, increased pressure by lateral forces causes, in general, chemical reactions and structural changes of rocks. For instance, if the initial rocks are of argillaceous nature, they acquire a sheetlike structure that changes them into schists, micaschists, or gneisses. Phenomena of metamorphism are complex, and I shall abstain from greater precision.

The main metamorphic rocks (gneisses and micaschists) are both crystalline and schistose. This is why they are sometimes called crystalline schists. Their schistosity distinguishes them from granite. The former neptunists had classified them as primitive rocks, adjacent to granite. A close relationship between granitic massifs is in fact often found because the granitic magma originated (at least in part) from the melting of crystalline schists when temperature and pressure were higher than those required for metamorphism.

longer exist at the surface of the earth. Deluc had similar views, and his refutation of uniformitarianism was based on his observation that successive epochs contained deposits of different nature. Earlier, Buffon had subdivided the history of the earth into "epochs" according to the nature of the various rocks formed during each epoch. This neptunist viewpoint could thus be called in a global sense the "geology of epochs," or "periodical geology."

Hutton had opposed this view, saying that granite was an igneous rock that had risen by intrusion, uplifting and folding younger deposits. The plutonist school had thus presented a cyclic theory in opposition to a periodic one. Lyell accepted this theory and gave the name *metamorphic rocks* to sedimentary rock units that had been modified by the rise of magma.[29]

The idea of metamorphism had been envisioned by Hutton. Leopold von Buch accepted the idea of rising magma (of **pyroxene porphyry**) to explain the formation of **dolostones** by chemical transformation of limestones. Metamorphism was thus believed to be the result of the action not only of temperature but also of vapors.

At any rate, the notion of primitive rock was on its way out. In

1842, T. Virlet d'Aoust was able to say that "all rocks so far called primitive, may well be only of second, or third origin, if not of an even younger one."[30]

However, a very strict uniformitarian would not be entirely able to follow this author because Virlet, as well as Élie de Beaumont and the French school, distinguished two metamorphisms: one, called "normal," was caused by the action of a central fire upon the deepest rocks, that is, primitive rocks; the other, "abnormal," resulted from the heat of periodically injected intrusive igneous rocks. This concept thus included the two characteristics of catastrophism: directionalism of phenomena and periodicity. Normal metamorphism was directionalist, with variations in intensity of the phenomenon over time; whereas abnormal metamorphism was characteristic of earth's revolutions, which were periodically repeated.

Lyell, however, continued to believe in the uniformity of all geologic phenomena. Contrary to the cyclical geology of catastrophists, he envisioned an orogenic activity of constant intensity, but which moved from one place to the other on earth over time. His geology was indeed steady state according to the definition given earlier in this chapter. Lyell was neo-Aristotelian, and we can thus characterize his adversaries as successors of the Stoics—so much so that the directionalist doctrine introduced an evolutionist dimension. Indeed, the new geological cycle was evolutionary because it maintained Werner's idea of a succession of periods, thus inheriting the historical approach. Lyell, on the contrary, advanced on a uniformitarian base.

To separate clearly the fundamental views of catastrophists and uniformitarians, we should stress that three kinds of observations were involved. First, metamorphism transformed sedimentary structures as well as fossil remains. Metamorphism thus tended to erase the archives. Catastrophists believed that its action was moderate in modern times, whereas Lyell, and Hutton even more so, considered its role permanent.

Second, erosion was one of the mechanisms of the Huttonian cycle. Lyell followed this docrine, though he stressed marine processes whereas Hutton was particularly concerned with the erosion of lands. Erosion also erased part of the archives. In general, catastrophists minimized the effects of running water. Narrow valleys were often believed to be fissures resulting from uplift, collapse, or deformation of rock formations.

The Didelphe of Stonesfield

Uniformitarianism called for an almost stable physical world and a biological universe with as little variation as possible to prove that animals could have lived in ancient times. However, since Cuvier it was known that fish preceded reptiles in the geological record and that reptiles lived before mammals. The question of the first appearance of mammals was therefore at the center of controversies about the uniformity of nature.

In 1812, fossil remains were found in calcareous shale at Stonesfield in England. Cuvier (1818) thought he recognized the jaw of a didelphe (etymologically meaning "two matrices," the term refers to marsupials who possess this anatomical characteristic). However, these rock layers were of Jurassic age, whereas it was generally believed that mammals had appeared at the beginning of the Tertiary era. The discovery thus supported the old age of mammals, namely, the uniformity of nature.

In 1824, Constant Prévost spent some time in England and sketched the jaw so that Cuvier could confirm his observation. However, Prévost was not sure that the fossil was of Jurassic age.

In 1831, Dufrénoy and Élie de Beaumont brought back a portion of a jaw, and everybody, including Cuvier, attributed it to a saurian. Thereafter, Ducrotay de Blainville reexamined the fossils and thought that they belonged to reptiles or fish, "which seems more in agreement with the age of the rock formation."*

It is known today that the jaws were those of authentic mammals—not of marsupials, but of forms, which lived before the separation of marsupials and real mammals (or eutherians), called panthotherians.

*Henri Ducrotay de Blainville, "Nouveaux doutes sur le prétendu Didelphe de Stonesfield," *Comptes Rendus, Académie des sciences de Paris* 7 (1838): 736.

The third observation concerned renewal of faunas. It was essential because renewal created archives, whereas the two other processes erased them. The theory of a gradual and uniform replacement of fauna supported by Lyell did not give much value to fossils. This is why it is fair to say that he was interested in stratigraphy in spite of his doctrine rather than because of it.

Drastic changes proposed by catastrophists had naturally quite opposite consequences. Catastrophists were therefore the real founders of biostratigraphy.